International Journal of Disaster Risk Reduction 32 (2018) 75–86

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Governing green change: Ecosystem-based measures for reducing landslide risk in Rio de Janeiro

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ARTICLE INFO

Keywords:
Rio de Janeiro
Informal settlements
Landslides
Governance
Eco-DRR/EbA
Ecological engineering

ABSTRACT

Ecosystem-based approaches are increasingly considered to reduce disaster risks (Eco-DRR) and adapt to climate change (EbA). Their consideration in some of the main global frameworks such as the IPCC report or the Sendai Framework for Disaster Risk Reduction has raised additional attention. However, these approaches are still more associated with rural than urban areas, although many urban areas face a high risk of natural hazards and the benefits of ecosystem-based measures to reduce it have already been proven in different cities.

A successful implementation of ecosystem-based approaches in urban areas is highly complex. Using the city of Rio de Janeiro as case study, we first examine on the municipality level the responsibilities of the different institutions involved in landslide risk reduction and their technical and organizational interfaces. In a second step we zoom into two marginal settlements to determine whether ecosystem-based measures for landslide risk reduction already exist and assess the potential to either implement or further increase their application. These so-called *favelas* are often constructed on or beneath steep and degraded slopes prone to landslides. Landslides are mainly triggered by heavy rainfall events which are likely to increase in the future due to the impacts of global climate change. Activities to reduce landslide risk are distributed between many different actors, such as civil defense, geological survey, urban planning, and environmental management, and the measures taken are predominantly engineered approaches with a focus on preparedness and response. The urban reforestation program which could provide additional ecosystem benefits is not yet aligned enough with risk reduction and faces several challenges. In addition, the consideration of informal settings in formal urban planning and management strategies can still be improved.

Based on quantitative and qualitative data from interviews and secondary sources, site visits, and expert interviews with representatives from public authorities and other stakeholders, the research assesses the individual institutional approaches as well as the overall urban governance system with regard to disaster risk reduction and climate change adaptation. The potential governance challenges for fostering ecosystem-based approaches are analyzed and clustered to provide an insight on paths that could facilitate the future consideration of Eco-DRR/EbA in Rio de Janeiro and beyond.

1. Introduction

Urban development can be very dynamic, especially regarding land use, resulting in a highly artificial space, often severe environmental degradation, and excessive consumption of natural resources - including the loss of ecosystem services. Urbanization processes often happen in informal ways, particularly in countries of the Global South. Such informality can result in marginal settlements in hazardous locations like flood-prone riverbanks or steep slopes, putting not only the communities at risk [1,2]; but at the same time challenging the implementation of risk reduction measures, in particular ecosystem-based solutions. Areas suitable for Eco-DRR and EbA measures, e.g. for flood retention or landslide protection are often densely built up, which hampers the implementation of such cost-effective and low-tech solutions.

Particularly in emerging and developing countries the exposure and vulnerability of urban populations to disaster events is high [3]. In some regions of the world climatic extreme events will likely increase in both frequency and intensity [4,5], which is the case in Southeast Brazil [6]. As a result heavy rainfall events will possibly trigger more

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https://doi.org/10.1016/j.ijdrr.2018.01.020
Received 1 June 2017; Received in revised form 4 January 2018; Accepted 18 January 2018
Available online 30 March 2018
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landslides than under the current climatic conditions. However most action still addresses either technical preparedness for a disaster or the assessment of its impacts. The major and most urgent need, however, is for the integration of risk reduction approaches in urban land use planning and the environmental management [3,7].

The sustainable management of urban areas requires the integration of actors from various sectors and from municipal, state and federal levels. It is therefore essential to analyze the urban governance system regarding disaster risk reduction (DRR) and climate change adaptation (CCA). A systematic assessment of the actors that are involved in formal as well as in informal ways, and the identification of their modus operandi and cooperation schemes is an integral and crucial component to facilitate the implementation of ecosystem-based approaches. This leads to the key question: how best to leverage Eco-DRR and EbA into the existing urban governance. In our case, it covers the assessment of actors involved in landslide risk reduction in marginal settlements, their responsibilities and common approaches, as well as their cooperation schemes and challenges in engaging more in ecosystem-based measures.

After the severe land and mudslides in April 2010 that caused more than 40 fatalities in the municipality of Rio de Janeiro, a paradigm shift started and several government institutions began to improve their services regarding disaster risk management. The progress that has been achieved since then is an improvement in early-warning including the operation of a new meteorological radar system, activities related to the preparedness of communities (evacuation routes, sirens for alerts), the development of "grey" infrastructure such as containment walls, as well as risk mapping for the potential removal of houses that are at high risk. Ecosystem-based solutions that integrate disaster risk reduction, climate change adaptation and the provision of other relevant ecosystem services are however so far not in the focus of urban planners and risk managers in Rio de Janeiro.

2. Background

2.1. Urban Eco-DRR/EbA and ecological engineering

Ecosystem-based approaches for disaster risk reduction (Eco-DRR) and adaptation to climate change (EbA) integrate the use of biodiversity and ecosystem services into an overall strategy to reduce people's vulnerability and increase their resilience to natural hazards and climate change [8]. Eco-DRR can be defined as *"the sustainable management, conservation, and restoration of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development."* [9:30]. EbA uses a similar ecosystem-based approach but focuses on the long-term adaptation to the adverse effects of climate change (Secretariat of the Convention on Biological Diversity 2009). Ecological engineering is understood as the *"design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both."* [10:365].

A rising number of case studies has proved the suitability of such approaches in different contexts [11,8]. The city of New York is implementing green infrastructures such as green roofs and rain gardens as an essential component for the urban stormwater management [12], the city of Coimbra, Portugal, that adopted a strategy to improve urban green spaces for food sovereignty and reduce urban flood risk [13] or Copenhagen, Denmark, that encourages various green infrastructures to delay water runoff and mitigate urban heat effects for both EbA and Eco-DRR [14].

There is growing awareness on the benefits of ecosystem services for sustaining livelihoods in urban contexts, e.g. on the modification of climate, hydrology or soil dynamics [15,16]. As a consequence different global frameworks stress the importance of ecosystem-based, nature-based or green solutions for urban risk reduction, among them the 2016 New Urban Agenda which promotes 'nature-based solutions' [17]. Urban green spaces and urban protected areas can contribute to mitigate risk impacts and support climate change adaptation and mitigation [18–22]. However traditional measures for disasters prevention, mitigation and recovery focus on 'grey' infrastructure like containment walls, channelization of rivers and other technical solutions [23–25]. This is especially true in densely inhabited urban areas [26].

The potential for ecosystem-based and hybrid solutions that combine grey and green approaches is increasingly recognized but has not been tapped fully yet. It could be a cost-efficient and feasible approach for risk reduction in urban areas as proven by a growing number of case studies (c.f. [20,27,28]). Notably marginal settlements could benefit from this, as ecosystem-based solutions, such as protection forests, are low-cost measures that can be implemented even by the communities themselves [29]. However, at the urban scale, a successful implementation of Eco-DRR/EbA measures requires not only technical knowledge and financial resources, but also an integration of environmental management, civil protection, and climate change adaptation into urban planning and governance. This represents a major challenge for cities of the global south with their high degree of informality.

2.2. Urban, risk and ecosystem governance

Since the mid-1990s the term governance is used to describe new emerging forms of societal organization and coordination, moving from a state-centered perspective towards the integration of actors from other societal sectors [30]. The United Nations Development Programme (UNDP) defined governance as *"the exercise of economic, political and administrative authority to manage a country's affairs at all levels"*. In general, governance comprises formal as well as informal mechanisms through which actors articulate their interests, exercise their legal rights, meet their obligations and/or mediate their differences (adapted from [31]).

However, there is a whole range of definitions of governance in urban, risk, or ecosystem governance. While good governance can be understood as *"participatory, consensus oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive"* and following *"the rule of law"* [31] good urban governance focalizes urban characteristics by defining it as *"based on the principle of urban citizenship, affirms that no man, woman or child can be denied access to the necessities of urban life, including adequate shelter, security of tenure, safe water, sanitation, a clean environment, health, education and nutrition, employment and public safety and mobility. Through good urban governance, citizens are provided with the platform which will allow them to use their talents to the full to improve their social and economic conditions"* [32].

This definition already covers the access to environment as an important part but in a rather consumeristic perspective without considering how to achieve and maintain these basic necessities as done in ecosystem thinking. A commonly used definition for ecosystem governance is *"…the means by which society determines and acts on goals and priorities related to the management of ecosystems,… [including] … the rules, both formal and informal, that govern human behavior in decision-making processes as well as the decisions themselves."* [33:5]. Similarly, there are definitions for risk governance or e.g. urban risk and adaptation governance defined as *"all modes and institutions by which a city's individuals, social groups and organizations of the state sector and the private domain negotiate their interests, exercise their influence and distribute as well as act upon their responsibilities to manage and reduce urban risk and to enable adaptation across all scales and actors in a city"* [34:56]. These definitions emphasize the actor-focused approach of governance in general. All are dynamic, situated in constantly changing surroundings, and have to respond to internal and external changes, often at different scales and across administrative boundaries, involving multiple authorities (cf. [33]).

Urban governance is already complex, particularly as growing cities exceed their administrative boundaries. Governance becomes even more complex when ecosystem management and DRR are required. A sustainable ecosystem management per se involves a range of actors, with different backgrounds, experiences, interests, mandates and

varying understanding of the functioning of ecosystems, their protection and of the possible responses [35]. Similarly EbA and Eco-DRR are anthropocentric concepts [36] that need to be supported within governance structures as pre-requisite for their successful implementation [37].

However, despite the key role of socio-economic and political interests and conditions for disaster impacts [7] related governance arrangements tend to receive little attention [38]. At their best Eco-DRR and EbA are implemented as an integrated element of a broader adaptation and risk reduction strategy [36], requiring a broadened governance involving multiple actors and thus complex negotiations within complex social networks, their formal and informal actors and structures [39,40]. Ecosystem-based approaches need a stronger consideration of the institutional, governance and policy context in which initiatives lie as Reid [29] argues in the case of EbA. Particularly poorer communities are reliant on ecosystems and their services; therefore community involvement is crucial for successful governance [29]. As a consequence making use of ecosystem services for DRR and CCA in urban areas also requires re-thinking in policy and governance [41,42].

2.3. Rio de Janeiro's urban landscape

Rio de Janeiro's urban landscape is characterized by a unique scenery [43], which at the same time exposes urban dwellers to various natural hazards and provides the topographical conditions for a fundamental polarization where rich and poor live close together [44].

Today, with a population of 6.48 million inhabitants in the municipality and 12.28 in the metropolitan region [45], Rio de Janeiro is Brazil's the second biggest urban agglomeration and the fourth biggest of South America. Of the 1224 km^2 of the municipality about 644 km^2 are urbanized and the rest is composed of forests, agricultural lands, and other land covers (Fig. 1). Although the city is one of the main economic hubs of Brazil a large share of the population is poor. Around 22% of the population [46] lives in one of the more than 1000 informal settlements called *favelas* [47].

Urban socio-spatial disparities date back to times when slaves had to work in the large plantations in and around the city and particularly the end of slavery in 1888 when many former slaves moved to cities like Rio de Janeiro. Disparities are still visible as upper middle and upper classes reside mostly on the flat lands near the sea while the marginal population occupy less desirable vacant areas. Thus, the spatial gradient of income distribution decreases from the South Zone with its core area between Copacabana and Barra da Tijuca district to the North and West, only disturbed by few fragmented pockets of informal settlements in the South Zone and middle class in the North and West Zone (Fig. 1).

The first informal settlement in Rio de Janeiro dates back to 1897 [48]. Since then their number has constantly grown and much of this growth has occurred on the environmentally fragile and risk-prone slopes of a coastal mountain range originally widely covered by Atlantic Forest *(Mata Atlântica)* [49,50]. In 2010, the municipality of Rio de Janeiro included as many as 1034 informal settlements [47] with a population of 1.443 million – around 22% of the total population [46]. Data of the Brazilian Institute of Geography and Statistics (IBGE) shows that between 2000 and 2010 the population growth of the informal settlements (19%) was almost four times than that of the formal city (5%) [47]. Such *favelas* often provide precarious living conditions with poor infrastructure [51], including a lack of sanitation potentially exacerbating slope destabilization. The often non-engineered houses add to the risk level due to poor foundations and resulting low capacity to withstand hazards like intense rainfalls and landslides.

The political handling of *favelas* has changed a lot over time. In the 1960s/70 s mass clearances of favelas in the South Zone resettled residents in social housing complexes in remote districts of the city which created new ghettos such as the City of God (*Cidade de Deus*) to a

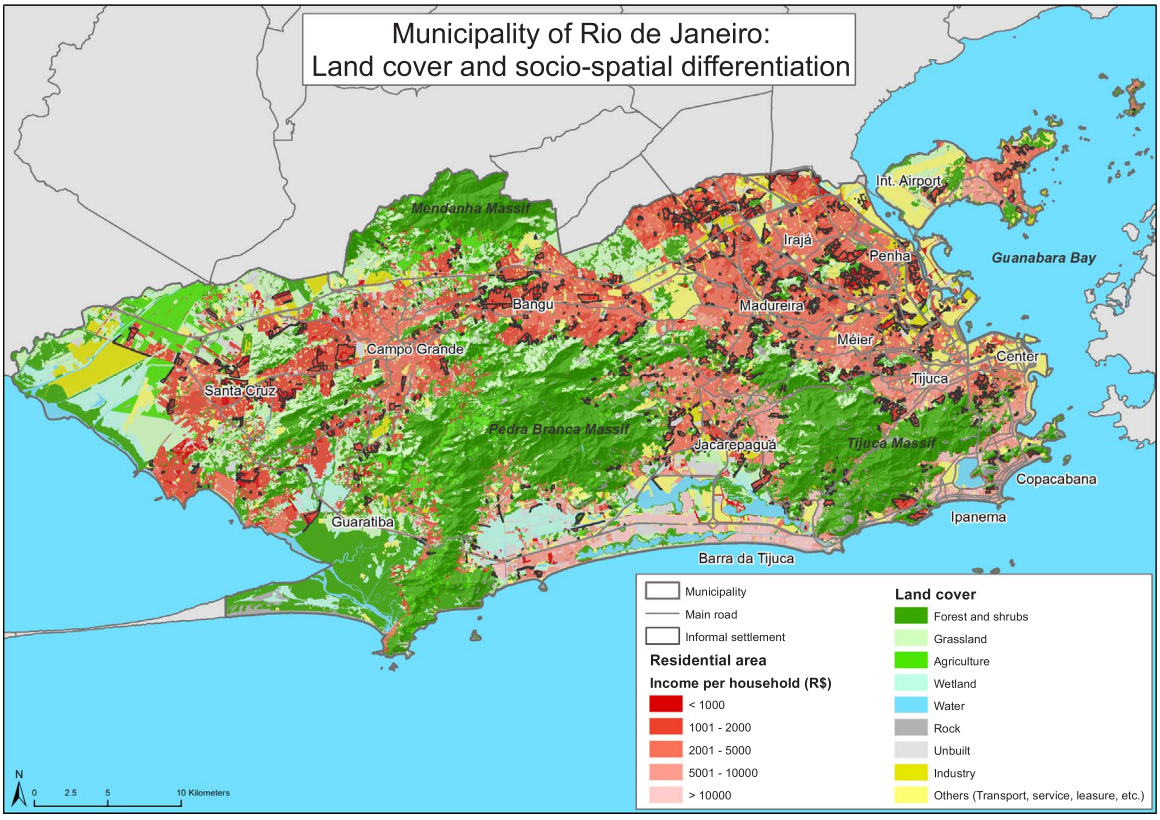

Fig. 1. Land cover and socio-spatial differentiation.
(Sources: [46,52], Cartography: W. Lange)

laissez-faire approach in the 1980s was followed by official recognition and the upgrading program Favela-Bairro in the 1990s; the Olympic Games in 2016, however, were followed by more broad removals [53]. This latest development is characterized by the attempt of the so-called pacifications of *favelas*, often with a massive police presence to reduce the crime rates. In reality the "pacification processes" did not achieve its goals and tensions between *favelas* and the rest of the city are still high.

One result of the past and ongoing expansion into environmentally vulnerable areas is environmental degradation. Despite awareness at the urban authority level of the need to address environmental aspects, in reality the environment is still often sacrificed for the sake of development processes or rather ignored in the context of marginal settlements.

2.4. Rio de Janeiro's landslide risk and climate change profile

The landscape of Rio de Janeiro is characterized by mountains and rock formations that are offshoots of the Serra do Mar as part of the Brazilian Highlands. Due to its natural conditions with a rugged topography, unstable geological features such as fractures and joints, as well as vulnerable weathering mantles and colluvial covers make the state of Rio de Janeiro prone to landslides and debris-flows [54–57] and has large areas that are highly susceptible to landslides (Fig. 2). Heavy rainfall events with up to 200–300 mm in 1–2 days occur in summer and are the main trigger for mass movements [58]. Over the last decades, several heavy landslides, mudslides and flood events caused casualties and severe material damage, undermining development gains. Within the city of Rio de Janeiro the worst events over recent decades in terms of victims occurred in 1967 with 110 fatalities [54,59] in 1988 with about 120 fatalities and 22,000 people who lost their houses [57], and in 2010 with 67 fatalities, hundreds of houses being destroyed, and severe damage to the urban road and traffic system [60].

Extreme meteorological events are the main triggering factors for landslides and floods and are not new to the region. Marengo [61] assumes that due to climate change frequency and intensity of these events have increased since the middle of the 20th century. Projections for the study region indicate that rainfall will increase by 20% until 2070 and by up to 30% until 2100 [62]. Consequently, climate change will likely increase disaster risk and vulnerability [63] in an already fragile region.

Intensity and impacts of landslide events are strongly affected by human intervention [64,65]. Investigations in the Tijuca National Park demonstrate that landslide susceptibility is considerably lower under preserved forest compared to degraded forests and grass or shrub cover [66]. Loss and degradation of forests is closely related to the expansion of illegal settlements. Fernandes et al. [67] showed that within a period of 30 years 47% of all landslides in the Tijuca Massif occurred in *favela* areas that are spreading into forested slopes. Overlaying the susceptibility map (Fig. 2) with the *favela* areas shows that about 981 ha are in highly susceptible areas where as in other residential areas only 177 ha are in highly affected areas [68]. Therefore the forest-urban interface and construction activities, particularly the sprawl of informal settlements and subsequent environmental degradation processes are in the focus when thinking about ecosystem-based measures for landslide risk reduction, even though some of the past landslides also occurred in legal residential area.

3. Methodology

The research used a mixed methodology approach with quantitative and qualitative methods. In a first step legislation, prevention and

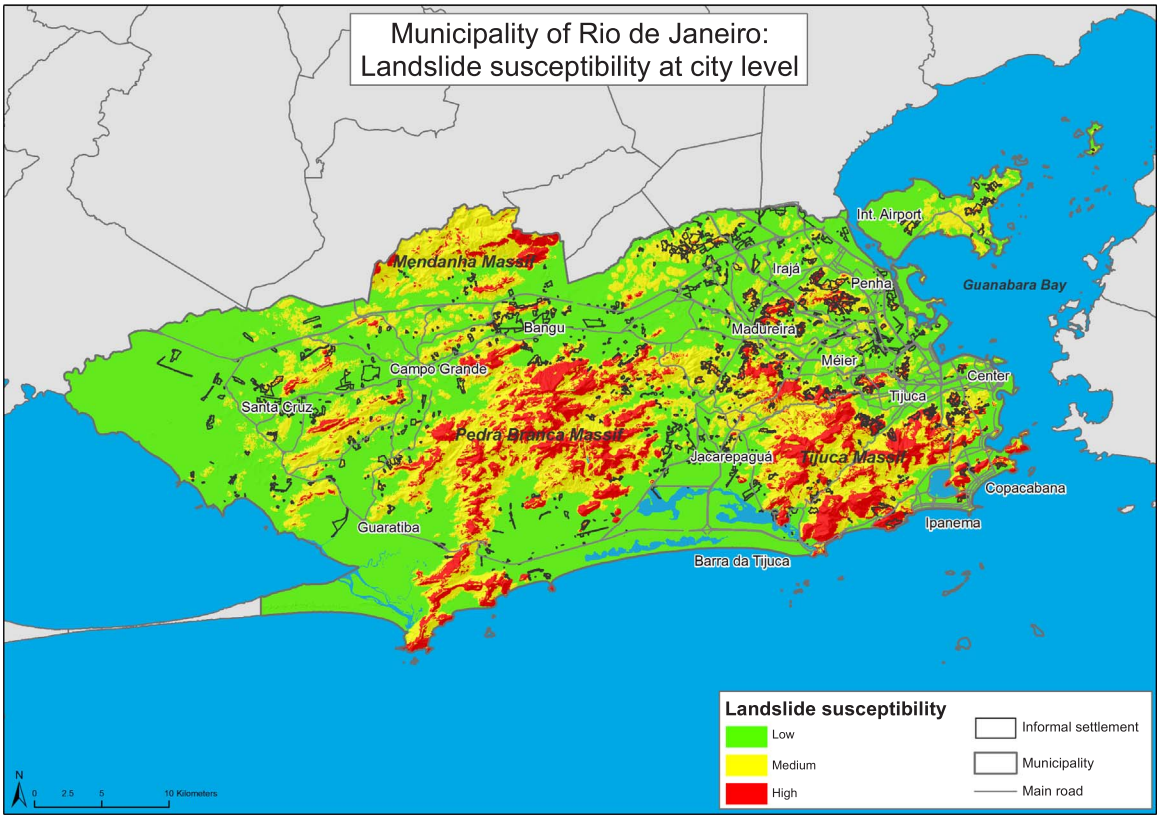

Fig. 2. Landslide susceptibility in Rio de Janeiro.
(Sources: [Geo-Rio 2015]; [52], Cartography: W. Lange)

mitigation plans and initiatives on state and local government levels as well as initiatives from other relevant actors and previous scientific publications on related topics were analyzed with respect to Eco-DRR and EbA and the governance system. In a second step twelve semi-structured expert interviews were conducted (Table A1 in the annex) between May 12 and 19, 2015, the interview length ranged from 25 min to 2.5 h; on average an interview took around 1 h 15 min To gain a deeper insight on processes, goals, policies and governance structures in relation to ecosystem-based approaches the interview guide was divided into the following sections (a) Landslide risk and underlying risk factors, (b) own perception of landslide risk, (c) relevant legal frameworks, (d) involved actors, their responsibilities and cooperation, (e) measures taken for risk prevention and mitigation by the respective organization and their effectiveness, (f) potential for Eco-DRR measures to reduce landslide risk and the (g) awareness of eco-DRR & Eco-DRR potentials and ways to facilitate their implementation. All interviewees are linked to disaster risk reduction, ecosystem management and/or climate change, either in responsible positions in state or municipal authorities, as members of civil society organizations or as researchers. The majority work for municipal authorities, namely the Geotechnical Institute *(Geo-Rio),* the municipal Water Institute *(Rio-Águas)*, the Civil Defense *(Defesa Civil)* as well as different departments of the Municipal Secretary of Environment *(SMAC)*. The subsequent structured content analysis of the transcribed interviews was done based on a pre-defined set of thematic clusters. It covered a range of categories, namely personal awareness and opinions regarding Eco-DRR and EbA, own work and organizational responsibilities related to landslide risk and ecosystem potentials, existing legal frameworks, prevention and mitigation plans and activities. Furthermore resulting shortcomings and conflicts with respect to consideration of ecosystem-based measures, and implemented measures for landslide risk reduction, their focal areas, perceived effectiveness and potential improvements were identified.

Additional site visits and on-site interviews were carried out in two local case studies, Morro da Formiga and Morro dos Prazeres in the North Zone of Rio de Janeiro (Zona Norte), which both had suffered from past landslide events including in the 2010 events. Case study area selection was based on preliminary data collection and analysis (as a part of research step one) as well as on input gained during expert interviews. In both *favelas* different formal measures to reduce the landslide risk have been implemented. Case study area assessments comprised field surveys and interviews with local actors as well as on-site inspections of affected areas and implemented measures. Each favela has been visited once with support from agents of the *Defesa Civil*. The visits have been guided by members of the favela association who have been interviewed as well, together with other community workers and local residents. Topics included, a part of disaster risk management, environmental management in general and awareness of ecosystem functions for disaster risk reduction as well as the reforestation activities in particular. In addition, available project data from various public authorities was collected and analyzed.

4. Results

4.1. Institutional framework

Different institutions (see Table 1) have been involved in DRR since a long time, having either an engineering (namely *Geo-Rio* and *Rio-Águas*) or a technical and social focus (*Defesa Civil*). In 2010, the operations center (*Centro de Operações* - COR) was established to allow for comprehensive monitoring, open data availability and thus improved risk and crisis management for the whole city serving as the coordinating institution for all early warning and response actions. With regard to risk reduction in informal settlements on steep slopes, a number of formal actors, namely such responsible for urban planning, environment, risk, infrastructure and social concerns, are involved. In addition, due to the often still informal character of the favelas, informal and formal local actors such as community-based initiatives are involved as well.

Among some of these actors formal or informal cooperation schemes have already been established, also most of these actors already have measures in their portfolio that can be considered as Eco-DRR and/or EbA (see Table 1).

4.2. Existing ecosystem-based and ecological engineering measures

Current ecosystem-based measures in the municipality of Rio de Janeiro focus on the reforestation program *Mutirão Reflorestamento* (reforestation by voluntary community work) of SMAC. The general mission of this program is to restore the vegetation cover of the Mata Atlântica biome in the city of Rio de Janeiro by recovering degraded and permanent protection areas. The program was initiated in the 1980s by the city hall to increase the quality of life in *favelas*. From the outset the program had a strong focus on social inclusion by employing workers from surrounding communities for reforesting the degraded land. Today the program functions as well via contracting private companies, environmental compensation or by mechanisms of tributary exemption (fiscal incentives).

Projects under *Mutirão Reflorestamento* primarily do not aim at reducing landslide risk, but biodiversity protection, embellishment and enhancement of ecosystem services, such as carbon sequestration, regulation of the water regime, and increasing scenic beauty. Consequently, these measures also seek to provide benefits for the communities, for instance by using fruits and medicinal plant organs (according to the reforestation expert from SMAC; oral information). They however do not link or expand to any structural grey measures although there would be a high potential particularly for the goals of reducing sediment flow preventing blocking of the drainage system and silting of rivers and channels as well as river bank stabilization.

Decision-making for a reforestation project is done based on a multi-criteria prioritization methodology taking into account different criteria like adjacency to existing forest fragments and to existing reforestation projects, proximity to informal settlements, area size and accessibility, slope orientation and inclination as well as landslide risk. These criteria are ranked by their importance based on a pre-defined scheme which rates landslide risk so far at the lowest value of four, whereas the adjacency to existing fragments and reforestation areas get the highest values of 19, indicating the low importance of landslide risk reduction in the program.

For the implementation itself planners and project staff are equipped with a manual for the identification of suitable native species. In its second edition, this manual includes 54 local tree species that are classified in four successional categories: pioneer species, initial secondary forest species, advanced secondary forest species, and climax species as well as two so-called functional groups, which include (a) fast growing trees with spreading treetops, and (b) slowly growing trees with less extensive canopies. In the beginning of each reforestation project fast growing pioneer trees with spreading treetops are planted to create shadow and force back grasses and other invasive species. After some years, these species get gradually replaced by species of advanced successional stages.

Data of the vegetation mapping of SMAC *(SIG Floresta)* shows that reforestation projects have been implemented in an area of 2158 ha. Unfortunately there is no information available on the success of the measures or what kind of vegetation is now predominating, thus hampering monitoring. Reforestation has been mainly implemented on

Table 1
Main actors and responsibilities related to landslides in informal settlements in 2015.
(Source: own table)

Actor	Function/responsibility	Usual action/measures in case of informal settlements at risk from landslides	Classification of approaches	Measures with Eco-DRR and EbA potential or already in existence
Defesa Civil Municipal (Civil Defense of the municipality)	Plan and coordinate action to reduce disasters in the municipality	Civil defense, focus on civil society activities, e.g. support of early warning and escape route systems, community-based preparedness, emergency response, rescue	Non-structural measures	Community-based awareness and preparedness activities
Geo-Rio - Fundação Instituto de Geotécnica do Rio de Janeiro (Foundation Institute for Geotechnics)	Municipal authority to monitor & stabilize slopes and take necessary measures, risk mapping	Lowering of risk level by means of engineered constructions like concrete walls, drainage, etc.	Structural 'grey' measures	'grey' interventions to reduce landslide risk
Rio-Águas - Fundação Instituto das Águas do Município do Rio de Janeiro (Foundation Institute for Waters)	Municipal water authority, responsible for management of rain water, flood prevention and sanitation in the West Zone	Flood and mudslide risk reduction	Structural 'grey' measures	Maintenance of waterways and 'grey' flood protection measures
SMAC - Secretaria Municipal de Meio Ambiente e Conservação (Municipal Secretariat for Environment and Conservation)	Municipal environmental agency, responsible for conservation, municipal protected areas and park/ garden management, environmental education reforestation and taxation	Reforestation of degraded hills to reduce landslide risk, maintenance of reforested parts, plantation activities in different succession steps, usually involving local communities in plantation and maintenance activities	Structural 'green' measures	Public environmental awareness campaigns and program for reforestation of slopes
SMH - Secretaria Municipal de Habitação (Municipal Secretariat for Environment)	Municipal housing authority	Potential relocation of buildings or communities at risk	Non-structural measures	Spatial planning and zoning
SMU-Secretaria Municipal de Urbanismo (Municipal Secretariat of Urbanism)	Municipal planning authority, responsible for urban planning, policies, land use planning and monitoring	Spatial planning and zoning	Non-structural measures	Risk-informed land use planning
COR - Centro de Operações (Center of Operations)	Operations and command center	Data collection and provision	Non-structural measures	Collection and provision of data
Academia	No formal responsibilities, potential advisors to authorities	–	Non-structural measures & research on structural ones	Collection, analysis and provision of data
Favela associations	Lead of local communities, contact persons for municipal authorities	Involved actors in activities like early warning, awareness campaigns, trainings and reforestation	Local scale structural 'green' & grey' as well as non-structural measures	Structural 'green' and 'grey' interventions in houses, plots and surrounding areas, e.g. reforestation, organization of awareness campaigns, trainings,

the northern parts of the Tijuca massif and to some extent as well in the northern part of the Pedra Branca Massif and on minor hills of the North Zone (cf. Fig. 1). By overlaying the areas of existing reforestation with the risk map of Geo-Rio (Fig. 2) it becomes visible that restoration measures have been implemented in 51% of areas with high, 47% with medium and 2% with low susceptibility [68].

The *Mutirão Reflorestamento* program is responsible for the coordination and implementation of reforestation measures. Apart from this NGOs and associations such as the *Associação dos Amigos do Parque Nacional da Tijuca* and the *Amigos do Parque Estadual da Pedra Branca* carry out reforestation projects. However, these organizations are more focused on conservation and environmental education. There is close and fruitful cooperation of *Mutirão Reflorestamento* with Geo-Rio (risk mapping), Rio-Águas (water management), and other units of SMAC in the establishment of reforestation projects, but poor cooperation with the urban planning unit, as pointed out by the reforestation expert. The program started almost 30 years ago and so far reforestation measures have been mainly implemented in unsettled, degraded large-scale areas and to a lesser extent in and around *favelas* (as reported in interview 07 with the responsible SMAC expert). However, according to the expert, further reforestation projects in *favelas* are planned.

Even though promising reforestation projects have already been established, there is a need to further explore the potential of ecosystem-based measures. So far, these measures primarily concentrate on classical reforestation projects combined with terracing and in some cases the additional use of geo-textile for slope stabilization what could be considered as ecological engineering. Other types of ecosystem-based measures including ecological engineering have not been implemented so far.

Apart from projects under the *Mutirão Reflorestamento,* there were no other projects on ecosystem-based landslide risk reduction in the municipality of Rio de Janeiro at the time of our field study. However, it should be mentioned that there were several projects focusing on land and ecosystem conservation and restoration, amongst them a Payment for Watershed Services project in the Guandu watershed that was already established in 2009. It aims at safeguarding the water supply for around eight million people in the city of Rio de Janeiro, but the conservation and restoration areas are located outside the municipality of Rio de Janeiro [69]. Moreover, the Brazilian National Forest Code (Lei n° 12.651, de 25 de maio de 2012) also aims at reducing the risk of geomorphic processes such as landslides by defining so called Áreas de Preservação Permanente (Permanent Preservation Areas - APPs). These APPs fulfil several functions in the landscape system, among them to secure geological stability. The law defines different types of APPs in both urban and rural environments. Important for landslide risk reduction are particularly those APPs that must be established (either conserved or restored with native or non-native vegetation) on slopes with a gradient > 45°. However, even though many marginal settlements are located on steep slopes, they do not always exceed 45°, and besides, it is rather difficult to map, monitor, and control these steep areas.

4.3. Governance challenges

The *Sistema Nacional de Unidades de Conservação – SNUC* (National System of Units of Conservation) defines protected areas such as National Parks and *Áreas de Proteção Ambiental - APAs* (Environmental protection areas), as well as various conservation categories under federal state and community legislation. Such status has to be considered when implementing reforestation projects. However, there are frequently overlaps of protection areas of various categories at national, state, and municipality level and also between the different sectors, e.g. environmental and urban planning legislation, which may lead to legal uncertainties and conflicts. Moreover, environmental laws and planning frameworks are often not respected, so that conflicts with illegal settlements are common (as stated by experts from SMAC). There is illegal agriculture in protected areas, induced by a lack of control and monitoring to take action against both illegal settlements and agricultural activities in protected areas.

In the future more small informal settlements will be considered in the reforestation program resulting in a need to revise the prioritization tool (as stated by interviewee 09, vegetation expert at SMAC). Moreover, Interviewee 07, in charge of the reforestation program, highlighted many positive experiences, but also emphasized some difficulties in the implementation, particularly scarce financial resources and the sometimes risky circumstances in *favelas*. He also expressed the benefits he sees in a closer cooperation with the urban planning authorities. The current urban governance system is not emphasizing integrated schemes which would bring together the expertise and skills of the different authorities for landslide risk reduction. Such concerted action can still be considered as exceptional, though promising attempts are in place.

At the same time lack of awareness regarding the potential of Eco-DRR and EbA measures as well as ecological engineering was identified as a major obstacle throughout the research. The majority of the interviewees were either unaware of potential ecosystem-based measures or regarded them as complementary to engineered solutions instead of an alternative. In this context the background of Geo-Rio in predominantly engineered approaches may be another obstacle that has to be overcome, the same is true for Rio-Águas which in addition is not

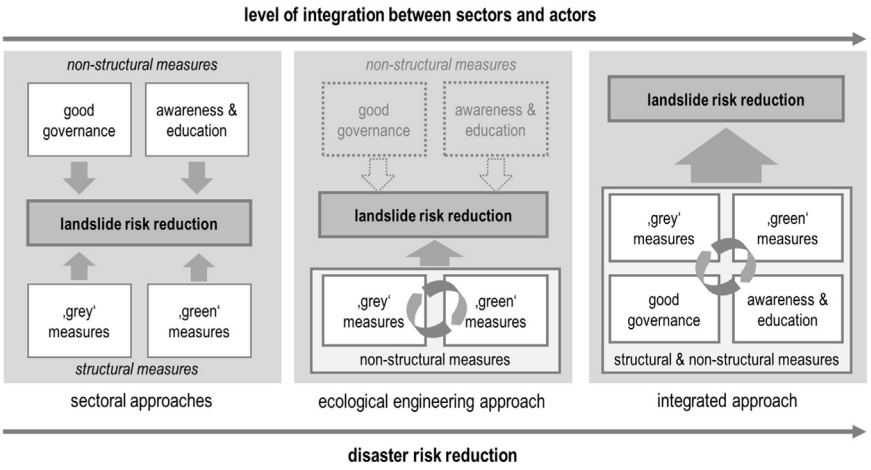

Fig. 3. Approaches for landslide risk reduction and respective level of integration.

even active in all *favela* areas. Besides that there is a lack of formal cooperation schemes, e.g. between Rio-Águas and Geo-Rio but also between these agencies and SMAC as well as Defesa Civil. If cooperation exists it is still often limited to data exchange.

Not all urban authorities address informal settlements. The expert interviews as well as the visits in Morro dos Prazeres (2100 inhabitants in 622 houses) and Morro da Formiga (4300 inhabitants living in overall 1300 dwellings, [70]) revealed particular challenges in informal settlements. Both favelas are located on steep slopes in the Tijuca massif and are facing high landslide risk due to its population density, a compact settlement structure with multi-storey buildings in steep slope positions and a lack of proper drainage system. Additional risk factors like landfills in steep slope positions, soil erosion and ongoing construction activities add to the risk level.

Risk reduction measures comprise early warning systems, evacuation routes, some concrete and brick walls with drainage tubes, slope sealing using shotcrete with drainage tubes to reduce infiltration and drain saturated soils, as well as some open sewage trenches that are

Table 2
Overview on potential ecosystem-based or hybrid measures and their governance challenges (based on [12,21,23,24,80–88]).

Ecosystem-based measure	Potential & suitability	(Potentially) involved actors	Challenges and/or implications for governance
Approaches with a predominant focus on ecosystem			
Reforestation of degraded areas	Can serve to stabilize slopes, to reduce erosion and to decelerate rain water runoff	SMAC, Local communities, Geo-Rio. Rio-Águas	• Prioritization for DRR/CAA needs should be multi stakeholder approach • Need to raise awareness of affected population to maintain the areas • Improve monitoring especially for DRR and CCA functions of reforested areas
Creation and management of combined agriculture and forestry	Would benefit local population and potentially increases participation processes in maintenance, can serve as commons that improve the livelihoods of the communities	Local communities, SMAC	• Need for environmental awareness and education • Improve intersectoral project development and monitoring
Measures on settlement & surrounding scale			
Waste management: composting of organic substances/avoidance of illegal dumping sites	Helps avoiding illegal dumping sites, and could contribute to regulated waste processing and reduced illegal dumping sites, potential to produce bio-fertilizer for reforested areas and urban agriculture	Local communities, NGOs, COMLURB, SMAC	• Need for environmental awareness and education • Dialogue between formal and informal actors and provision of technical skills to informal dwellers
Hybrid measures on house/settlement scale			
Green roofs	Could serve to reduce & decelerate rainwater runoff, beneficial for building climate	Local communities, external experts on construction technique and suitable plants (municipality or NGO)	• Need for environmental awareness and education • Technical skill
Grey water harvesting and re-use	Could serve to reduce water runoff and subsequent erosion, water might be used to water plants on green roofs and urban agriculture	Local communities, urban authorities (particularly SMU, Rio-Águas)	• Need for environmental awareness and education • Connecting *favelas* to formal water supply and sewage • Dialogue between formal and informal actors
Rain water harvesting	Could serve to reduce & decelerate rainwater runoff and subsequent erosion, additional potential for reducing downhill flooding	Local communities, urban authorities (particularly SMU, Rio-Àguas)	• Need for environmental awareness and education • Connecting *favelas* to formal water supply and sewage
Unsealing/ facilitation of rain water infiltration	Unsealing of asphalted/built-up areas could benefit more even water infiltration and reduced erosion	Local communities, urban authorities (particularly SMU, Rio-Àguas)	• Need for environmental awareness and education • Connecting *favelas* to formal water supply and sewage
Social/administrative measures			
Awareness campaigns – for authorities and population	Authorities and population are not yet aware of ecosystem potentials to reduce risks, awareness raising campaigns could support the use of such measures	Local communities, all involved urban authorities, NGOs	• Eco-DRR measures potentially require the involvement and cooperation of different institutions over time • Better integration of all relevant stakeholder • Increase multidisciplinary thinking on holistic approach
Trainings for local communities	Trainings on local scale measures	Local communities, experts	• Commitment of local population, probably best to be linked to awareness campaigns
More systematic integration of ecosystem status in consideration of adequate measures in disaster inventories	Consider ecosystem potentials already in early stage of decision-making	Geo-Rio	• Better integration and information exchange with SMAC
Research	Fill knowledge and data gaps with respect to efficiency and effectiveness of different ecosystem-based measures (such as selection of best tree species for risk reduction), economic aspects (such as financing of Eco-DRR/EbA, and PES) as well as social aspects (such as social/ societal potentials and hindrances for Eco-DRR/ EbA)	Universities, research institutes	• Promote trans- and multidisciplinary approaches to research • Encourage cooperation between social and natural sciences • Encourage a holistic approach to problem solving that takes into account different scales and range of socioeconomic conditions and effects • Produce research outcomes that are relevant and accessible for society

mainly located along the steep stairways. Ecosystem-based measures are limited to a reforestation project by SMAC in Morro dos Prazeres. Active involvement of favela dwellers exists in case of the reforestation where local staff is hired and in the risk preparedness measures of Defesa Civil (as explained in interviews 05 and 07).

Overall, cooperation between the local and the urban or federal state level as well as between formal and informal actors is limited in Rio de Janeiro. Formal urban planning schemes of the responsible authorities (SMU) are rarely focusing on favelas. As a consequence, individual measures on the local level are rarely integrated in larger programs and have limited impact also due to a lack of knowledge, skills, budget, long-term perspectives and available land. Such constraints are particularly bad for ecosystem-based approaches which need a longer time to develop their full potential and which often are more space-intensive than engineered ones.

5. Discussion

There is a wide portfolio of ecosystem-based measures that may help to reduce the risk of landslides and other natural hazards in Rio de Janeiro's hilly areas, in particular mudslides and floods. These solutions can complement the existing engineered structures or can even make technical solutions redundant. Linking the different sectors and actors that are already actively involved in risk reduction has the potential to multiply the impacts and develop more resistant and durable strategies (cf. Fig. 3). However, it should also be emphasized that there is an urgent need to clearly proof the effectiveness and efficiency of ecosystem-based measures - such as protection forests - for landslide risk reduction. For the case of Rio de Janeiro there are so far only a limited number of studies that demonstrate the protective functions of an intact forest cover or the higher vulnerability of a degraded vegetation cover, respectively [64–67]. However, so far there is no evidence for effective landslide risk reduction (or protection) of reforested areas and also no efficiency comparison of green and grey measures. Even at the international scale such research is very limited. Among the few publications that focus on the effectiveness of protection forests are mainly studies from Europe, North America and East Asia (among others [71–79]) that cannot be transferred one to one to humid tropical climate conditions. The lack of studies should however not be confused with a lack of protective functions.

Regardless of their potential ecosystem-based approaches are hardly considered so far. One of the main challenges is the high level of informality in Rio de Janeiro which excludes important actors from decision-making and hinders different authorities from being actively engaged in areas at risk from landslides. Namely security issues regarding the armed domination of the territory of favelas and their surroundings have been mentioned by interviewees to impede a broader implementation of the reforestation program. On the other hand, as ecosystem-based measures generate several co-benefits, their implementation and acceptance could be more fruitful if accompanied by awareness raising campaigns. A part of the environmental co-benefits of *Mutirão Reflorestamento* it contributes to the income generation as part of the workers are paid and social networking among other social benefits. Actually, the reforestation program has been initially implemented by the Municipal Secretary of Social Development. Other obstacles include land scarcity in urban areas, limited financial resources, a lack of awareness of decision-makers regarding the suitability of ecosystem-based approaches and their benefits, and higher confidence in hard infrastructure impede their implementation.

Despite the given potential of ecological engineering a sole focus on linking ‘green’ and ‘grey’ measures would fall short (cf. Fig. 3). Most challenges for considering such measures are rather governance-related. Overall, it is recommendable to better integrate Eco-DRR/EbA into formal urban planning strategies that also address and actively include informal dwellers. To overcome silo thinking it is necessary to reconsider entrenched structures and cooperation schemes. Novel governance approaches are needed, bringing together actors from different specialist backgrounds as well as from different social groups and scales (cf. Fig. 3, right side).

Main constraints for implementing ecosystem-based approaches include the comparably long time span until the full protective function is achieved. While hard infrastructure, such as protective walls and drainage systems are immediately functional, a closed vegetation cover needs some time to develop, and during this growth phase the landslide risk remains comparably high. Moreover, there is still a higher acceptance and trust in engineered structures than in natural solutions, particularly in countries like Brazil, where forests are associated with risk and uncertainty. Environmental education and awareness initiatives may help to reduce some fears; but on the other hand it cannot be denied that for instance wildfires and snakes are threats to residents when forests are close to the settlements. Also landslides have occurred under well-preserved forest, making it clear that protection forests cannot completely eliminate landslide risk. This is also true of engineered structures, however, since in some cases protection walls have collapsed, drainage systems have clogged, and shotcrete has been washed out (Table 2).

6. Conclusion

Rio de Janeiro has projects or initiatives in place that could be considered as Eco-DRR and/or EbA. The successful urban reforestation program in particular has the potential to reduce landslide risk while also supporting the livelihoods of local communities. However this potential for Eco-DRR and/or EbA is yet to be fully exploited, e.g. co-benefits for local communities that may benefit from agricultural or forestry products. Here participatory approaches and awareness campaigns on co-benefits could be a suitable tool.

One of the main hindrances for ecosystem-based or ecological engineering measures identified in the course of the study is the still predominant silo approach of urban authorities, which stick to traditional approaches and – equally important – communication and cooperation schemes. This issue is particularly apparent between more engineering-focused perspectives of Geo-Rio and Rio-Águas, and the more environmental-based background of SMAC. To address these inefficiencies, new urban governance approaches are needed that overcome sectoral thinking and promote ecosystem-based approaches for DRR that serve the local communities. It is recommendable to build upon both, those cooperation schemes that already exist as well as on the existing personal understanding of experts in the different involved authorities and to consolidate them.

One general conclusion that can be drawn from the Rio de Janeiro case is that it is not sufficient to take a look only at the existing knowledge on Eco-DRR/EbA, but that this has to be seen in the context of the existing governance system with its formal and informal communication and decision-making structures. Governance is a crucial point for ecosystem-based approaches in urban areas, as a proper planning and implementation would require bringing together engineering, environmental and DRR communities in a joint effort.

Acknowledgement

The research presented here was carried out with financial support of the Lincoln Institute of Land Policy.

Annex

(See Table A1).

Table A1
List of interview partners.

No	Institution
01	*Governo do Estado do Rio de Janeiro, Secretaria de Desenvolvimento Econômico, Energia, Indústria e Serviço- Serviço* Geológico do Estado – *DRM-RJ* State Government of Rio de Janeiro, Secretary of Economic Development, Energy, Industry and Services – Rio de Janeiro Geological Survey – DRM-RJ
02	*Secretaria Municipal de Meio Ambiente – SMAC,* Coordenadoria de Fiscalização Ambiental – MA/CGCA/CFA Municipal Secretary of Environment, Environmental Monitoring Coordination
03	*Secretaria Municipal de Obras Fundação Instituto de Geotécnica – Geo-Rio* Municipal Secretary of Construction Works, Geotechnical Institute – Geo-Rio
04	*Centro de Operações,Prefeitura do Rio, Programa Rio Resiliente* Center of Operation, Rio de Janeiro Municipality, Program 'Resilient Rio'
05	*Secretaria da Saúde e Defesa Civil, Subsecretaria de Defesa Civil* Secretary of Health and Civil Defense, Sub-Secretary of Civil Defense
06	*Fundação Instituto das Águas do Município do Rio de Janeiro – Rio-Águas* Water Institute of Rio de Janeiro Municipality – *Rio-Águas*
07	*SMAC – Coordenadoria de Recuperação Ambiental – MA/CRA*, Programa Mutirão *Reflorestamento* SMAC – Environmental Restoration, Reforestation program
08	*SMAC - Coordenadoria de Conservação e Proteção Ambiental – MA/CPA* SMAC – Environmental Conservation and Protection Coordination
09	*SMAC - Coordenadoria de Conservação e Proteção Ambiental – MA/CPA* SMAC – Environmental Conservation and Protection Coordination
10	*Secretaria Municipal de Obras Fundação Instituto de Geotécnica – Geo-Rio* Municipal Secretary of Construction Works, Geotechnical Institute – Geo-Rio
11	*Pontifícia Universidade Católica do Rio de Janeiro – PUC-Rio, Departamento de Arquitetura e Urbanismo, Instituto de Pesquisas em Infraestrutura Verde e Ecologia Urbana* Pontifical Catholic University of Rio de Janeiro, Department of Architecture and Urbanism
12	*Universidade Federal do Rio de Janeiro – UFRJ, Departamento de Geografia, Laboratório de Geomorfologia* Federal University of Rio de Janeiro – UFRJ, Department of Geography, Geomorphology Laboratory

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